505.00 PILING

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A check of the Contractor's pile driving equipment, accessories, and the piling must be done before any piling is driven. The hammer cushion material type, dimensions and condition should be checked before pile driving begins to verify consistency with the wave equation analysis. The Contractor shall not drive any piling until the foundation excavation is complete, and the materials acceptance requirements per the Quality Assurance Manual, Item 505, are provided for each piling type to be used.

Piles shall be driven at locations as shown in the plans. Minimum pile spacing shall be as shown in the project plans. The inspector should check the plumbness and the location of each pile during installation. Piles shall be driven with a variation in alignment of not more than 0.25 in./ft. (21 mm/m) from the vertical or from the batter shown on the plans. However, the pile top plan location, at cutoff level, shall not deviate more than 6 in. (150 mm) in any direction from the location shown in the plans. For steel H-piles, pile orientation is very important because the lateral resistance to bending of these piles depends on the flange direction. The inspector should check the orientation of the H-piles to ensure that rotational deviation is not more than 30 degrees from that shown in the plans. Notify the Geotechnical Engineer/Field Services Engineer at the Headquarters Materials Section of any driven pile that becomes damaged or does not meet the above criteria, so that a determination may be made for any necessary corrective actions.

In plastic soil, pile heaving may occur when adjacent piles are driven. For this reason, the inspector should check elevations on pile groups after they are driven. Any piles that have heaved more than ¼ inch (6 mm) shall be re-driven to the required pile capacity before the piling group is accepted.

Minimum penetration may be difficult to obtain when driving piles through granular fills, very dense sand and gravel formations, boulders, or certain silts. If refusal occurs before minimum penetration is obtained, the Contractor may be required to try a larger hammer size or pre-bore the hole, depending on the contract requirements.

Pile points or shoes may be needed to help piles penetrate hard soils or key into bedrock. Current approved products lists may be obtained from the Geotechnical Engineer or Field Services Engineer at the Headquarters Materials Section.

When pre-boring is employed, the borehole should be smaller than the pile, and should be stopped short of the minimum required pile penetration. Pre-boring should generally be stopped at the highest pile tip elevation as shown on the plans, or as directed. The piling must be driven to its final position. In very hard materials, such as bedrock, the bored hole is generally slightly smaller than the pile diameter and should be stopped at the design pile tip elevation. The pile is then driven to refusal. The annulus of the bored holes in rock shall be grouted to the rock surface. The rest of the bored holes can be backfilled with grout or pea gravel, or other approved materials.

Vibratory hammers can be used to drive piles but must be stopped at least 3 ft. (1 m) above the estimated pile tip elevation as shown on the plans, or as directed. An impact hammer must then be used to drive piles to the required tip elevation or to the required pile bearing.

- **Steel Pipe Piling:** Steel pipe piles shall be carefully checked for wall thickness, and outside and inside diameter. Diameter and thickness of end closures also shall be checked. After driving, the pile should be checked for damage that may occur during driving. Either lowering a light to the bottom of the pipe or using a mirror to reflect sunlight into the pile interior can do this. Pipe piles should be covered, after driving, to keep out debris. Piles that contain water must either be pumped or bailed out just prior to placing concrete, or the concrete must be placed under the water by an approved tremie method.

- **H-Piling:** H-piles shall be handled so as to prevent bending the flanges, and shall be supported when stacked for storage so they will not be damaged. H-piles shall be checked for correct sectional dimensions, square ends, straightness, and constant width between flanges throughout the length of the pile.

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Splicing

- **Timber Piles:** Contact the Geotechnical Engineer/Field Services Engineer in the Headquarters Materials Section before permitting splices.
- **Steel Piles:** Splicing will be allowed upon approval of the splicing method by the Bridge Section. Unless otherwise approved, the minimum pile section length that will be allowed for splicing will be 10 feet (3 m).

Markings

All piles should be marked in increments sufficient to determine bearing capacity and penetration at all elevations. Usually a blue or yellow keel or paint stick is satisfactory for marking the piling. On greasy, treated timber piling, spray paint generally gives the best results.

Pile Hammers

Pile hammers are normally of the following types:

- **Gravity or Single Acting Steam/Air Hammer:** Employs a cable, or steam, or compressed air to raise the hammer and has a driving energy equal to the weight of the ram multiplied by the height of the fall.
- **Double Acting Steam/Air Hammer:** Employs steam (or compressed air) to raise the hammer and to accelerate the hammer on its downward fall.
- **Diesel Hammer, Open End:** Returns the hammer by an explosion of diesel fuel at the time of impact, which increases the impact or driving energy furnished to the pile.
- **Diesel Hammer, Closed End:** In the upward flight of the ram, compressed air in the bounce chamber forms an "air spring" to force/accelerate the ram downward.

Before using a pile hammer, the brand name and model number of the hammer should be identified. The necessary data on ram weight, fall or length of stroke, air/steam pressure, or bounce chamber pressure for closed end diesel hammers, and hammer cushion material must be obtained and checked. Use the information on the ITD-969, Pile Driving Hammer Data Needed for Wave Equation Analysis form (Exhibit 505-1) that was previously submitted by the Contractor for the wave equation analysis. Any change in the hammer system may require a new wave equation analysis to be run by the Headquarters Materials Section. The condition, size, and material type of the hammer cushion must be checked. A compressed, worn or damaged hammer cushion, or hammer cushion material that is other than as submitted by the Contractor shall be replaced.

During driving, the hammer should be checked for proper operation. The stroke length should be checked for single acting air/steam hammers and open end diesel hammers, and the proper air/steam pressure should be obtained for double acting air/steam or closed end diesel hammers. Since the resistance to pile penetration determines the height of return for the ram on diesel hammers, the stroke length or delivered energy will increase with increasing resistance. The rated energy will not be developed until the hammer is at full stroke. The driving energy cannot be accurately determined where large penetrations per blow occur.

The stroke length on open-ended diesel hammers is directly proportional to the blows/minute delivered by the hammer. Stroke lengths can be calculated from the blows/minute using a Saximeter that records the blows acoustically and then calculates stroke length from the blows/minute. Contact the Geotechnical Engineer/Field Services Engineer in the Headquarters Materials Section if you need a Saximeter.

Closed end diesel hammers show increasing bounce chamber pressure with increased energy. To determine the energy developed, monitor the bounce chamber pressure. A Saximeter may be used for counting blows, but will not be of value in determining driving energy. The bounce chamber pressure may require correction for altitude and hose length.

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Safe driving operations require that equipment be in good condition and that workers are safety-conscious. Cables, connections, and safe handling of the piling and the pile driving system should be observed. The inspector must be especially careful when making measurements in the area around pile driving operations. The operator and workers should be made aware of the inspector's presence at all times.

Ordering Piling

The Standard Specifications require that the Contractor order piling after the Engineer has authorized the length of piling needed for the project. If test piles are set up on the project, the authorized pile lengths should be based on the test pile data. The Geotechnical Engineer/Field Services Engineer in the Headquarters Materials Section will authorize the pile length(s) after reviewing the test pile record and estimating the pile length(s) needed to meet the project pile capacity requirements.

If test piles are not set up, the Engineer should base the authorized piling length on the estimated pile lengths indicated on the plans. Pile lengths should be based on test pile results or the lengths shown on the plans, not on the lengths the Contractor prefers to order. Standard pile lengths are 40, 50, or 60 ft. (12, 15, or 18 m). When ordering piles, consideration should be given to minimizing the splices and cutoff lengths, and utilizing all of the piling.

Should the Contractor choose to order the pile before the test piles are driven, the Contractor should be informed in writing that full responsibility for the length and quantity of piling is now given to the Contractor.

Determining Pile Bearing Capacity

The wave equation analysis shall be used for determining pile bearing capacity. Necessary data on pile driving equipment (Exhibit 505-1) must be submitted to the Geotechnical Engineer/Field Services Engineer in the Headquarters Materials Section two weeks in advance of pile driving so that the wave equation analysis can be performed. The wave equation analysis is used to determine the hammer driving capacity, prepare the pile driving criteria, and evaluate stroke, penetration resistance, bounce pressure, driving stresses, etc. If the proposed hammer is judged not adequate for the job, the Contractor shall be required to use a different hammer. The Contractor should be requested to provide this information at the preconstruction conference. If you are unable to obtain wave equation analysis results, the Engineer should use the dynamic formula in the Standard Specifications to estimate pile bearing capacity. The Headquarters Materials Section will forward wave equation analysis results to the Districts. Results shall include the following:

- Graph showing pile capacity versus blow count per last 1 foot and/or 1 inch (0.3 meter and/or 25 mm) of driving (see Exhibit 505-7). This graph will generally show curves for different hammer stroke heights for single acting steam/air or open end diesel hammers, or bounce pressure for closed end diesel hammers. Graphs may be sent for various pile lengths since the wave equation is based on definite pile lengths for bearing computations. Use the graph that corresponds to the piling length being driven.
- Graph showing stresses induced in the piles during driving versus stroke or blow counts. This graph can be used to determine the maximum stroke or blow count that should not be exceeded to prevent pile damage (Exhibit 505-7).

The penetration resistance for refusal or for the required pile capacity will be shown in the cover letter, (Exhibit 505-6), accompanying the pile capacity graphs. The pile refusal criteria are established to minimize potential damage, particularly where piles are driven into rock. The inspector shall count the number of blows at the last 1 foot or 1 inch (0.3 m or 25 mm) of driving (or measure pile penetration in the last ten blows) and apply that count to the graph to determine the pile bearing capacity. For single acting steam/air or open end diesel hammers, the stroke height of the ram shall be observed or determined using a Saximeter so as to use the proper curve in the graph.

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The required pile capacity must be achieved in at least two consecutive 1-foot (0.3-m) penetration intervals before driving can be stopped. When piles are driven to refusal or in very hard or dense materials, the blow counts could be very high, and in these cases blow counts per 1-inch (25-mm) intervals instead of per 1-foot (0.3-m) intervals can be used to determine pile bearing. If the wave equation analysis indicates that a pile might be overstressed and damaged at a certain blow count and/or stroke, this level of driving resistance must never be exceeded.

In driving battered piles, the stroke height must be adjusted to compensate for the increased ram friction and inclination. A stroke height adjustment graph is generally attached to the letter transmitting the pile driving criteria, or can be found in the operating manual of the Saximeter.

Notify the Geotechnical Engineer/Field Services Engineer in the Headquarters Materials Section as soon as possible when any driven pile achieves design bearing at a penetration of less than 50% or more than 150% of the estimated pile penetration shown in the plans. Adjustments may be needed in the pile driving criteria.

Pile Stresses

Any driven pile must remain structurally intact and not be stressed to its structural limits during both its service life (static capacity) and during driving (dynamic capacity). This requires that limits be placed on (1) maximum allowable design stresses during the service life, and (2) maximum allowable driving stresses during installation (temporary). In most cases, the highest stress levels will occur in a pile during driving. Therefore, pile damage often occurs because of excessive stress levels generated in the pile during driving.

Two methods available for determining driving stresses are (1) wave equation analysis, and (2) use of a dynamic pile driving analyzer during pile driving. Ideally, the maximum allowable driving stress value permitted by the specifications should be based on the accuracy and reliability of the method used for determining the actual driving stresses. Two sets of recommendations may be required: (1) for projects where design and construction control is only by wave equation analysis (lower maximum allowable driving stress values); and (2) for projects where a wave equation analysis is used for design and a dynamic pile driving analyzer is used for construction control (higher maximum allowable driving stresses). To keep the recommendations simple and clear, only one set of recommendations is provided assuming that only a wave equation analysis is used for both the design and construction control. The following discussion of allowable pile driving stresses is grouped into two categories:

- **Steel H, Steel Pipe (Top Driven), and Steel Monotube Piles:** The published literature generally recommends limits on driving stresses (tension and compression) of ≤ 0.9 Fy, where Fy is the yield strength of the steel.
- **Timber Piles:** Timber is known for its ability to withstand transient loads, such as pile driving. This factor must be tempered somewhat by the fatigue properties of timber piles.

Recommendations

The recommended maximum allowable driving stresses for steel H, steel pipe (top driven), and steel monotubes are as follows:

- Maximum tensile and compressive driving stress = 0.9 Fy

A wave equation analysis is recommended during the design stage to estimate pile driving stresses and to make sure that the pile cross-section is sufficient for obtaining necessary embedment without exceeding the maximum allowable driving stress limits recommended above.

In easy driving situations (small resistance to pile driving), high tensile stresses are generated. Make sure that the tensile driving stress limitation is not exceeded. Typical easy driving situations are (1) at the beginning of driving, and (2) when the pile penetrates into soft or loose soil layers which offer little resistance to the pile tip.

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In hard driving situations (high resistance to pile driving), high compressive stresses are generated. Make sure that the compressive driving stress limitation is not exceeded. Typical hard driving situations are (1) at the end of driving for end-bearing piles, and (2) when the pile penetrates into very dense soil or rock layers. If pile driving becomes difficult and refusal is met before the required tip elevation is obtained, pile driving should be stopped and the Geotechnical Engineer/Field Services Engineer at the Headquarters Materials Section should be consulted; otherwise, piling may be damaged.

The wave equation analysis and/or preferably, the dynamic pile driving analyzer are recommended for construction control of the pile driving. The wave equation analysis will provide an estimate of the driving stresses generated, whereas the dynamic pile driving analyzer will measure the actual driving stresses for each hammer blow during driving.

Pile Splices

Refer to the plans and specifications to determine how splices are to be made. Generally, splices are not paid for if they are for the Contractor's convenience. However, payment for splices may be more practical and economical when cutoffs become excessive, and the payment for cutoffs exceeds the cost of a splice.

Piling lengths exceeding 60 ft. (18 m) will usually require a splice. Depending on piling quantities authorized to be ordered, the depth driven, cutoff lengths, etc., will be factors in determining if any splices will be paid for each pile. An analysis should be made to determine splicing cost versus cutoff lengths before making the decision to splice or waste cutoffs. However, no more than two (2) splices prior to driving will be paid for by the state. Unless otherwise approved, the minimum pile section length that will be allowed for pile splicing will be 10 feet (3 m).

Documentation for Pay Quantity

The ITD-792, Summary Report of Pile Driving (Exhibit 505-4), shall be the source document for pay quantities. The ITD-970, Test Pile Record (Exhibit 505-2), is used for test piles. The diary shall be used to verify the activity, date, and location of the work. Piling shall be measured and reported to the nearest 1 foot (0.3 meter).

Reports

The following reports are required for pile driving:

- ITD-970, Test Pile Record, (Exhibit 505-2). If a test pile is required, the intent of this form is to present a log of the pile bearing capacity throughout its penetration depth. Sufficient readings should be taken to permit plotting a graph of bearing versus penetration. A separate report is required for each test pile. Handwritten reports, neatly prepared, are acceptable; and recopying is discouraged. Enough information should be furnished about the hammer being used to permit subsequent recalculation of the bearing values.
- ITD-971, Individual Pile Driving Record, (Exhibit 505-3). This form is used to record data for each production pile driven.
- ITD-972, Pile Driving Summary Report, (Exhibit 505-4). The summary of pile driving is shown on this report.
- ITD-973, Pile Driving Summary Report (Pile Layout), (Exhibit 505-5). This form shows the driven pile locations along the structure centerline.

ITD 0969 (Rev. 12-03)

Pile Driving Hammer Data
For Wave Equation Analysis

Exhibit 505-1

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All fields marked with * must be completed. This data is essential to the analysis.

umber*	Project Number*	Project Name*
	ABC-1234(000)	

Location*
town Road Bridge

Hammer

Manufacturer*	Model*	Lead Width* – in (mm)
ICE	42-S	26 (660)

Type*	Rated Energy* – ft·lb (Joules)
Open End Diesel	42,000 (57000)
Ram Weight – kip (kg)	**Maximum Stroke – ft (m)**
4.09 (1820)	10.27 (3.13)

Strike Plate

Weight – kip (kg)*	Thickness – in (mm)
0.345 (157)	
Cross Section Area – in^2 (mm^2)	

Hammer Cushion

Material*	Thickness – in (mm)*
Nylon	2.0 (50.8)
Cross Section Area – in^2 (mm^2)*	**Elastic Modulus – ksi (MPa)**
398 (257000)	175 (1207)
Coefficient of Restitution*	
0.92	

Helmet – Including Adaptor

Weight – kip (kg)*
2.09 (950)

Pile Cushion (For Concrete Piles Only)

Material*	Thickness – in (mm)*
NA	NA
Area – in^2 (mm^2)*	**Elastic Modulus – ksi (MPa)**
NA	NA
Coefficient of Restitution*	
NA	

Data Submitted By	Company
Jim Jones	ECI
Phone Number	**Date**
123-456-7890	June 9, 2003

Distribution: ☐ Regional/Resident Engineer (Original) ☐ Central Materials (Geotechnical Engineer)

ITD 0970 (Rev. 6-03)

Test Pile Record

Exhibit 505-2

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mber	Project Number	Project Location

e ation Ground ace n)	Vertical Hammer Stroke ft (m)	Blow Per ft (0.3 m)	Blow Per in (25 mm)	Pile Capacity kip (kN)

Hammer Make and Model	Rated Energy – ft·lb (Joules)	
Pile Type	Pile Size	Pile Length – ft (m)
Tip Protector	Pile Number	Abutment/Pier Number
Ground Line Elevation – ft (m)	Required Pile Capacity – kip (kN)	

Pile Penetration – ft (m)

Pile Capacity – kip (kN)

Remarks

Date	Inspector

Distribution: ☐ Regional/Resident Engineer (Original) ☐ Central Materials (Geotechnical Engineer)

ITD 0971 (Rev. 6-03)

Individual Pile Driving Record

Exhibit 505-3

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umber	Project Number	Project Location	
ent/Pier Number	Pile Number	Tip Protector	
pe	Pile Size	Pile Length – ft (m)	Cut Off – ft (m)
t Off Elevation – ft (m)	Pile Tip Elevation – ft (m)	Design Load – kip (kN)	
er Type	Manufacturer	Model	Rated Energy – ft·lb (Joules)

le ration r in mm)	Hammer Stroke ft (m)	Blows Per ft or in (0.3 m or 25 mm)	Pile Capacity kip (kN)

Pile Penetration ft or in (m or mm)	Hammer Stroke ft (m)	Blows Per ft or in (0.3 m or 25 mm)	Pile Capacity kip (kN)

Remarks

Weather	Date	Inspector

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ITD 0972 (Rev. 6-03)

Pile Driving Summary Report
Pile Length And Capacity

Exhibit 505-4

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umber	Project Number	Project Location

ype	Pile Size	Tip Protector

er Type	Manufacturer	Model	Rated Energy – ft·lb (Joules)

ent er ber	Pile Number	Date Driven	Pile Length ft (m)	Cut Off ft (m)	Net Length ft (m)	Vertical Hammer Stroke ft (m)	Blow Per ft or inch (0.3 m or 25 mm)	Pile Bearing Capacity kip (kN)	Pile Design Load kip (kN)

Remarks

Date	Inspector

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☐ Contract Administration

ITD 0973 (Rev. 6-03)

Pile Driving Summary Report
Pile Layout

Exhibit 505-5

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umber	Project Number	
Location		
pe	Pile Size	Tip Protector
er Type	Manufacturer	Model
/eight – kip (kg)	Maximum Stroke – ft. (m)	Rated Energy – ft·lb (Joules)

yout

℄

ks

Date	Inspector

Distribution: ☐ Regional/Resident Engineer (Original) ☐ Central Materials (Geotechnical Engineer) ☐ Bridge
☐ Contract Administration

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-500 11-94 **Exhibit 505-6**

IDAHO TRANSPORTATION DEPARTMENT
Department Memorandum

TE: September 2, 2004 **Project No.(s):** ABC-1234(000)

: JOE DOE, P.E.
DIST. 8, REGION 3 ENGR. **Key No.(s):** 4321

OM: JOHN W. DOE, P.E.
FIELD SERVICES ENGINEER

Project Id., County, Etc.:
BRIDGETOWN ROAD BRIDGE
SLOUGH COUNTY

: PILE DRIVING CRITERIA

owing are the pile driving criteria for the referenced project. The criteria were developed assuming that an ICE S diesel hammer will be used to drive HP 12x74 (310x110), steel H piles for all piers and abutments through rs of gravel, sand and silt. All of the piles will terminate in either very dense sand or hard clay that underlies the iously mentioned soil layers.

piles shall be driven to the minimum bearing capacity of 160 Kips (712 kN), provided in the Driving Data in project plans.

ommended minimum blow counts for production piles for both the abutments and the piers are as follows:

ROKE, FT (M)	BLOWS/ 1' (0.3M)	BLOWS/ 1" (25MM)
8.5 (2.60)	153	13
9.0 (2.74)	125	11
9.5 (2.90)	106	9
10.0 (3.05)	92	8

ommended minimum blow counts for pile driving refusal for test piles are as follows:

ROKE, FT (M)	BLOWS/ 1' (0.3 M)	BLOWS/ 1" (25MM)
8.5 (2.60)	200	17
9.0 (2.74)	185	16
9.5 (2.90)	170	14
10.0 (3.05)	140	12

For batter piles, the hammer strokes will need to be adjusted using the attached graph.

The attached graph shows the WE analysis results. **Also, please note that the ICE 42-S hammer will be operating at relatively high strokes to achieve bearing within a reasonable blow count. Therefore, if the hammer will not operate at the required stroke after piles have reached the minimum tip elevation, we should be contacted immediately to revise our pile driving criteria if necessary.**

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PILE CAPACITY VS. BLOW COUNT
BRIDGETOWN ROAD BRIDGE

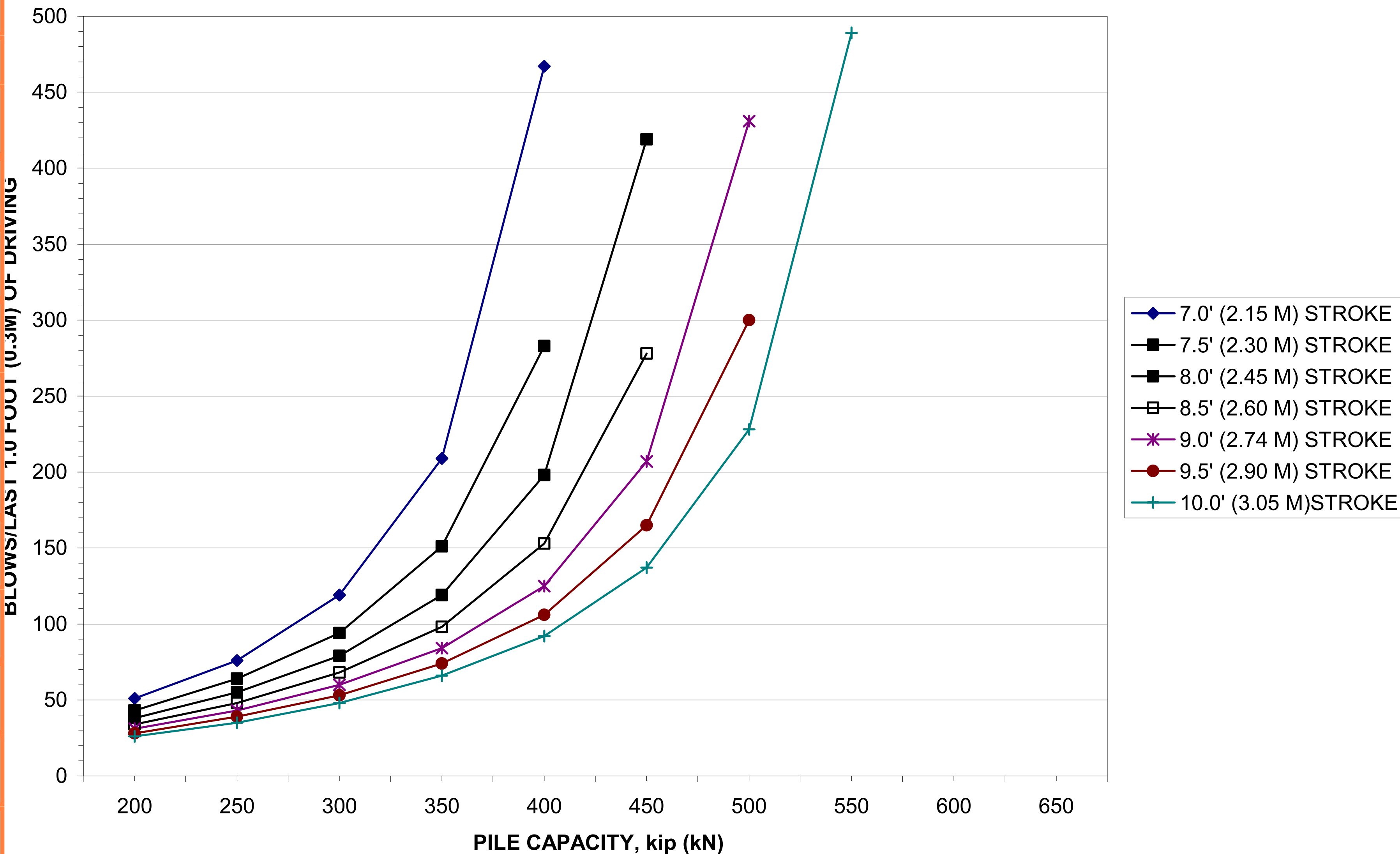

Exhibit 505-7